

FORM PTO-1390  
(REV 11-98)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371

WATK: 213

U.S. APPLICATION NO. (If known, see 37 CFR 1.51)

09/889375

INTERNATIONAL APPLICATION NO.

PCT/JP00/080440

INTERNATIONAL FILING DATE

15 November 2000

PRIORITY DATE CLAIMED

19 November 1999

TITLE OF INVENTION

HONEYCOMB STRUCTURE

APPLICANT(S) FOR DO/EO/US

Takashi HARADA; Yukio MIYAIRI

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
  - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☒ has been transmitted by the International Bureau.
  - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
  - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☐ have been transmitted by the International Bureau.
  - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
  - d. ☐ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.  
☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information:  
International Application Cover Page.  
PCT Request.

PLEASE ACCEPT THIS AS  
AUTHORIZATION TO DEBIT  
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DEP. ACCT. 16-0331  
PARKHURST & WENDEL

U.S. APPLICATION NO. **09/889375**

INTERNATIONAL APPLICATION NO.  
PCT/JP00/08044

ATTORNEY'S DOCKET NUMBER  
WATK: 213

17. ☒ The following fees are submitted:

**BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5) ) :**

Neither international preliminary examination fee (37 CFR 1.482)  
nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO  
and International Search Report not prepared by the EPO or JPO ..... \$1,000.00  
International preliminary examination fee (37 CFR 1.482) not paid to  
USPTO but International Search Report prepared by the EPO or JPO ..... \$860.00  
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but  
international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... \$760.00  
International preliminary examination fee paid to USPTO (37 CFR 1.482)  
but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... \$690.00  
International preliminary examination fee paid to USPTO (37 CFR 1.482)  
and all claims satisfied provisions of PCT Article 33(1)-(4) ..... \$100.00

**ENTER APPROPRIATE BASIC FEE AMOUNT =**

**CALCULATIONS PTO USE ONLY**

\$ 860.00

\$

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30  
months from the earliest claimed priority date (37 CFR 1.492(e)).

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE
Total claims	18 - 20 =	0	X \$18.00
Independent claims	1 - 3 =	0	X \$80.00
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ \$270.00

**TOTAL OF ABOVE CALCULATIONS =**

\$ 860.00

Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement  
must also be filed (Note 37 CFR 1.9, 1.27, 1.28).

\$

**SUBTOTAL =**

\$ 860.00

Processing fee of \$130.00 for furnishing the English translation later than ☐ 20 ☐ 30  
months from the earliest claimed priority date (37 CFR 1.492(f)).

\$

**TOTAL NATIONAL FEE =**

\$ 860.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be  
accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property

\$

40.00

**TOTAL FEES ENCLOSED =**

\$ 900.00

Amount to be:

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\$

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a. ☒ A check in the amount of \$ 900.00 to cover the above fees is enclosed. CK# 14250

b. ☐ Please charge my Deposit Account No. \_\_\_\_\_ in the amount of \$ \_\_\_\_\_ to cover the above fees.  
A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any  
overpayment to Deposit Account No. 16-0331. A duplicate copy of this sheet is enclosed.

**NOTE:** Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR  
1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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SIGNATURE

Charles A. Wendel

NAME

24,453

REGISTRATION NUMBER

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

Takashi HARADA et al.

Serial No.: New Application

Filed: July 16, 2001

For: HONEYCOMB STRUCTURE

PRELIMINARY AMENDMENT

Commissioner for Patents  
Washington, D.C. 20231

Sir:

Prior to examination of the above-identified application,  
please enter the following specification changes as noted below:

IN THE CLAIMS:

Please amend claims 5, 7-14 and 16-17 as follows:

5. (Amended) A honeycomb structure according to Claim 1,  
wherein each slit is exposed to at least one end surface so as to  
connect the two points of the end surface edge.

7. (Amended) A honeycomb structure according to Claim 1, wherein each slit is exposed to the outer surface over its total length in the through-hole direction.

8. (Amended) A honeycomb structure according to Claim 1, wherein in each section of the honeycomb structure including each slit there is a continuous area in which no slit is formed and which is not exposed to the outer surface of the honeycomb structure.

9. (Amended) A honeycomb structure according to Claim 1, wherein in the honeycomb structure section which is normal to the through-holes and in which the length of each slit is largest, the length of each slit is 10% or more of the distance between the outer surface along the axial direction and the center of the honeycomb structure.

10. (Amended) A honeycomb structure according to Claim 1, wherein in the honeycomb section which is normal to the through-holes and in which the length of each slit is largest, the length of each slit is 30% or more of the distance between the outer

surface along the axial direction and the center of the honeycomb structure.

11. (Amended) A honeycomb structure according to Claim 1, wherein each slit is filled with a filler.

12. (Amended) A honeycomb structure according to Claim 1, which is a combination of two or more honeycomb segments.

13. (Amended) A honeycomb structure according to Claim 1, which is made of a material containing, as a main crystal phase, at least one kind selected from the group consisting of cordierite, SiC, SiN, alumina, mullite, aluminum titanate and lithium aluminum silicate.

14. (Amended) A honeycomb structure according to Claim 1, which loads thereon a metal having a catalytic action and is usable for purification of the exhaust gas emitted from a heat engine or a burner, or for reforming of a liquid fuel or a gaseous fuel.

16. (Amended) A honeycomb structure according to Claim 1, wherein the sectional shape of the through-holes is any of a triangle, a tetragon, a hexagon and a corrugation.

17. (Amended) A honeycomb structure according to Claim 1, wherein the partition walls surrounding the through-holes have a filtration ability, a given proportion of the through-holes are blocked at one end and the remaining through-holes are blocked at other end.

REMARKS

Claims 1-18, as amended, remain herein. Claims 5, 7-14 and 16-17 have been amended hereby.

This Preliminary Amendment is submitted to eliminate multiply dependent claims from the above-identified application.

Examination of this application on its merits is respectfully requested.

Respectfully submitted,

PARKHURST & WENDEL, L.L.P.



Charles A. Wendel

Registration No. 24,453

July 16, 2001

Date

Attachment:

Mark Up of Amended Claims

CAW/ame

Attorney Docket No. WATK:213

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# Claims

1. A honeycomb structure having a large number of through-holes formed in the axial direction and defined by partition walls, wherein slits are formed so as to be exposed to at least part of the outer surface of the honeycomb structure along the axial direction.
2. A honeycomb structure according to Claim 1, wherein the slits are formed in parallel to the direction of the through-holes.
3. A honeycomb structure according to Claim 1, wherein the slits are formed at least at one end surface at least at the edge.
4. A honeycomb structure according to Claim 3, wherein the length of each slit formed at the edge of one end surface is, in the axial direction of the outer surface, 10% or more of the total length of the honeycomb structure and, at the end surface, 10% or more of the diameter of the honeycomb structure.
5. A honeycomb structure according to ~~any of Claims 1 to 3~~ Claim 1, wherein each slit is exposed to at least one end surface so as to connect the two points of the end surface edge.
6. A honeycomb structure according to Claim 5, wherein the length of each slit is, in the axial direction of the outer surface, 10% or more of the total length of the honeycomb structure and, at the end surface, 10% or more of the diameter of the honeycomb structure.
7. A honeycomb structure according to ~~any of Claims 1 to 6~~ Claim 1, wherein each slit is exposed to the outer surface over its total length in the through-hole direction.
8. A honeycomb structure according to ~~any of Claims 1 to 7~~ Claim 1, wherein in each section of the honeycomb structure including each slit there is a continuous area in which no slit is formed and which is not exposed to the outer surface of the honeycomb structure.
9. A honeycomb structure according to ~~any of Claims 1 to 8~~ Claim 1, wherein in the honeycomb structure section which is normal to the



through-holes and in which the length of each slit is largest, the length of each slit is 10% or more of the distance between the outer surface along the axial direction and the center of the honeycomb structure.

- 5 10. A honeycomb structure according to ~~any of Claims 1 to 9~~ Claim 1, wherein in the honeycomb section which is normal to the through-holes and in which the length of each slit is largest, the length of each slit is 30% or more of the distance between the outer surface along the axial direction and the center of the honeycomb structure.
- 10 11. A honeycomb structure according to ~~any of Claims 1 to 10~~ Claim 1, wherein each slit is filled with a filler.
12. A honeycomb structure according to ~~any of Claims 1 to 11~~ Claim 1, which is a combination of two or more honeycomb segments.
13. A honeycomb structure according to ~~any of Claims 1 to 12~~ Claim 1, which is made of a material containing, as a main crystal phase, at least one kind selected from the group consisting of cordierite, SiC, SiN, alumina, mullite, aluminum titanate and lithium aluminum silicate.
- 15 14. A honeycomb structure according to ~~any of Claims 1 to 13~~ Claim 1, which loads thereon a metal having a catalytic action and is usable for purification of the exhaust gas emitted from a heat engine or a burner, or for reforming of a liquid fuel or a gaseous fuel.
- 20 15. A honeycomb structure according to Claim 14, wherein the metal having a catalytic action is at least one kind selected from Pt, Pd and Rh.
- 25 16. A honeycomb structure according to ~~any of Claims 1 to 15~~ Claim 1, wherein the sectional shape of the through-holes is any of a triangle, a tetragon, a hexagon and a corrugation.
17. A honeycomb structure according to ~~any of Claims 1 to 16~~ Claim 1, wherein the partition walls surrounding the through-holes have a
- 30 filtration ability, a given proportion of the through-holes are blocked

at one end and the remaining through-holes are blocked at other end.

18. A honeycomb structure according to Claim 17, which is used as a filter for capturing and removing the particulate matter contained in a dust-containing fluid.

10/PR75

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JC18 Rec'd PCT/PTO 1 6 JUL 2001

## DESCRIPTION

### Honeycomb Structure

#### 5 Technical Field

The present invention relates to a honeycomb structure for catalyst loading, used in an exhaust gas purifier of a heat engine (e.g. an internal combustion engine) or a burner (e.g. a boiler), a reforming unit of a liquid fuel or a  
10 gaseous fuel, and the like; as well as to a honeycomb structure used as a filter.

#### Background Art

Honeycomb structures having a catalyst component loaded  
15 thereon have been used in an exhaust gas purifier of a heat engine (e.g. an internal combustion engine) or a burner (e.g. a boiler), a reforming unit of a liquid fuel or a gaseous fuel, and the like. It is known that honeycomb structures are also used as a filter for capturing and removing the  
20 particulate matter contained in a dust-containing fluid such as exhaust gas emitted from a diesel engine.

The honeycomb structures used for such purposes have had problems; for example, they undergo rapid temperature change or local heating by the action of an exhaust gas, an  
25 uneven temperature distribution appears therein, resultantly they come to have cracks. Particularly when they were used as a filter for capturing the particulate matter contained in the exhaust gas emitted from a diesel engine, cracks appeared easily because the carbon fine particles accumulated on the  
30 filter must be burnt for removal and it inevitably causes

local heating to high temperatures and easily generates a large thermal stress. In this case, the thermal stress is generated because the uneven temperature distribution allows different portions of the honeycomb structure to have  
5 different thermal expansion deformations and resultantly each portion is restricted by each other and is unable to make free deformation.

To reduce the stress, there was proposed, in, for example, JP-A-59-199586, a honeycomb structure having a large  
10 number of through-holes each surrounded by partition walls, wherein partition wall areas having at least one slit are formed at given portions of the honeycomb structure almost uniformly.

In this proposal, small slits are distributed uniformly  
15 in a honeycomb structure, thereby the rigidity of the total honeycomb structure is reduced and the freedom of deformation is increased, therefore an effect of stress reduction is achieved. However, the degree of an increase in the freedom of deformation is insufficient; therefore, the above proposal  
20 for stress reduction was insufficient for a honeycomb structure used under severe conditions where the unevenness of temperature distribution becomes larger.

In view of the above-mentioned problems of the prior art, the present invention aims at providing a honeycomb  
25 structure which gives no cracks by thermal stress during use and which is superior in durability.

#### Disclosure of the Invention

According to the present invention there is provided a  
30 honeycomb structure having a large number of through-holes

formed in the axial direction and defined by partition walls, wherein slits are formed so as to be exposed to at least part of the outer surface of the honeycomb structure along the axial direction.

5 In the above honeycomb structure, the slits are formed preferably in parallel to the direction of the through-holes. Also, preferably, the slits are formed at least at one end surface at least at the edge. By forming the slits in this way, each portion of the honeycomb structure can deform  
10 freely without being restricted by other portion even when an uneven temperature distribution appears therein; as a result, reduction in thermal stress is possible and generation of cracks can be prevented.

In this case, more preferably, the length of each slit  
15 formed at the edge of one end surface is, in the axial direction of the outer surface, 10% or more of the total length of the honeycomb structure and, at the end surface, 10% or more of the diameter of the honeycomb structure.

It is also preferable that each slit is exposed to at  
20 least one end surface so as to connect the two points of the end surface edge, because such a honeycomb structure has an increased freedom for deformation in the vicinity of the end surface, reduction in thermal stress is possible, and generation of cracks is prevented. In this case, more  
25 preferably, the length of each slit is, in the axial direction of the outer surface, 10% or more of the total length of the honeycomb structure and, at the end surface, 10% or more of the diameter of the honeycomb structure.

When the present honeycomb structure is used under such  
30 conditions that the total (total length) of the honeycomb

structure comes to have a temperature unevenness, it is preferable that each slit is exposed to the outer surface over its total length in the through-hole direction.

When the total of the honeycomb structure comes to have a large temperature unevenness, it is particularly preferable that each slit is formed so that in each section of the honeycomb structure including each slit there is a continuous area in which no slit is formed and which is not exposed to the outer surface of the honeycomb structure.

In the honeycomb structure of the present invention, it is preferable that in the honeycomb structure section which is normal to the through-holes and in which the length of each slit is largest, the length of each slit is 10% or more, preferably 30% or more of the distance between the outer surface along the axial direction and the center of the honeycomb structure.

In the honeycomb structure of the present invention, it is preferable that each slit is filled with a filler. It is also preferable that the present honeycomb structure is a combination of two or more honeycomb segments.

The above honeycomb structure is preferably made of a material containing, as a main crystal phase, at least one kind selected from the group consisting of cordierite, SiC, SiN, alumina, mullite, aluminum titanate and lithium aluminum silicate.

Preferably, the present honeycomb structure loads thereon a metal having a catalytic action and is usable for purification of the exhaust gas emitted from a heat engine (e.g. an internal combustion engine), a burner (e.g. a boiler) or the like, or for reforming of a liquid fuel or a

gaseous fuel. The metal having a catalytic action is preferably at least one kind selected from Pt, Pd and Rh.

In the present honeycomb structure, the sectional shape of the through-holes is preferably any of a triangle, a tetragon, a hexagon and a corrugation from the standpoint of the production of the honeycomb structure.

When the present honeycomb structure is used as a filter for capturing and removing the particulate matter contained in a dust-containing fluid, for example, as a particulate filter for diesel engine, it is preferable that the partition walls surrounding the through-holes have a filtration ability, a given proportion of the through-holes are blocked at one end and the remaining through-holes are blocked at other end.

In the present invention, "the outer surface of the honeycomb structure" refers to the whole outer surface of the honeycomb structure and includes not only the outer surface along the axial direction but also the end surfaces.

## Brief Description of the Drawings

Fig. 1 is perspective views showing examples of the honeycomb structure according to the present invention.

Fig. 2 is perspective views showing other examples of the honeycomb structure according to the present invention.

Fig. 3 is perspective views showing still other examples of the honeycomb structure according to the present invention.

Fig. 4 is perspective views showing still other examples of the honeycomb structure according to the present invention.

Fig. 5 is perspective views showing still other examples of the honeycomb structure according to the present invention.

Fig. 6(a) is a perspective view showing still other example of the honeycomb structure according to the present invention. Fig. 6(b) is a view taken along the Y-Y section of Fig. 6(a).

Fig. 7(b) is a perspective view showing still other example of the honeycomb structure according to the present invention. Fig. 7(b) is a view taken along the Z-Z section of Fig. 7(a).

Fig. 8(a) shows a method for slit formation and indicates a state in which slits are formed in parallel to partition walls. Fig. 8(b) indicates a state in which slits are formed so as to cut partition walls obliquely.

Fig. 9(a) shows a stress-relaxing mechanism provided at the front end of each slit, i.e. a stress-relaxing portion having a curvature provided at the front end of each slit. Fig. 9(b) shows branches provided at the front end of each slit.

Fig. 10(a) shows a form of slit formed by cutting part of partition walls. Fig. 10(b) shows a form of slit formed by removing part of partition walls.

Fig. 11(a) is a plan view showing an example of the disposition of slits in the honeycomb structure of the present invention; Fig. 11(b) is a front view of the example; Fig. 11(c) is a side view of the example; and Fig. 11(d) is a bottom view of the example.

Best Mode for Carrying Out the Invention



The honeycomb structure of the present invention has a large number of through-holes formed in the axial direction and defined by partition walls, wherein slits are formed so as to be exposed to at least part of the outer surface of the honeycomb structure. Therefore, the present honeycomb structure generates no cracks by the thermal stress appearing during the use and is extremely superior in durability.

The present invention is described in more detail below with reference to the embodiments shown in the accompanying drawings. However, the present invention is in no way restricted to these embodiments.

Figs. 1(a), (b), (c) and (d) are perspective views showing embodiments of the honeycomb structure of the present invention.

In Figs. 1(a), (b), (c) and (d), 10 is a honeycomb structure. The honeycomb structure 10 has a large number of through-holes 11 formed in the axial direction [an X direction in Figs. 1(a), (b), (c) and (d)] and defined by partition walls. In the honeycomb structure 10, four slits 12 are formed so as to be exposed to part of the outer surface 13 along the axial direction and be parallel to the direction of the through-holes 11. Each slit 12 is formed so as to cross the edge 15 of the end surface 14.

In Fig. 1(a), four slits 12 are formed so as to cross the edge 15 of the end surface 14 and each in the shape of a triangle. In Fig. 1(b), each slit 12 is formed in the shape of a tetragon. In Fig. 1(c), each slit 12 is formed so as to be exposed to the axial direction total length of the outer surface 13 along the axial direction of the honeycomb structure 10 and so that the depth of the slit 12 becomes

gradually smaller and each slit has a triangular shape. In Fig. 1(d), each slit 12 is formed so as to be exposed to the axial direction total length of the outer surface 13 along the axial direction of the honeycomb structure 10 and so that the depth of the slit 12 becomes constant in the axial direction of the honeycomb structure 10. By forming slits 12 as shown in Figs. 1(a), (b), (c) and (d), each portion of the honeycomb structure 10 can deform freely without being restricted by other portion even when an uneven temperature distribution appears in the honeycomb structure 10 (that is, temperature difference exists between the portions of the honeycomb structure 10); thereby, the thermal stress is reduced; and generation of cracks is minimized.

In Fig. 2(a), three slits 12 are formed. As in Fig. 1(c), each slit 12 is formed so as to be exposed to the axial direction total length of the outer surface 13 along the axial direction of the honeycomb structure 10 and so that the depth of the slit 12 becomes gradually smaller and each slit has a triangular shape. In Fig. 2(b), three slits 12 are formed and, as in Fig. 1(d), each slit 12 is formed so as to be exposed to the axial direction total length of the outer surface 13 along the axial direction of the honeycomb structure 10 and so that the depth of the slit 12 becomes constant in the axial direction of the honeycomb structure 10. These embodiments are particularly effective when the honeycomb structure is used under such conditions that an uneven temperature distribution appears over the total length of the honeycomb structure.

Figs. 3(a) and (b) are perspective views showing other examples of the honeycomb structure of the present invention.

In the example of Fig. 3(a), slits 12 are formed so as to be exposed to one end surface 14 and connect the two points (A and B) or (C and D) of an end surface edge 15. In the example of Fig. 3(b), slits 12 are formed at two end surfaces 14 and 16 so as to be exposed to each of them and connect each two points of an end surface edge 15.

Figs. 4(a), (b), (c) and (d) are perspective views showing still other examples of the honeycomb structure of the present invention.

In each example of Figs. 4(a), (b), (c) and (d), in each section of a honeycomb structure 10 including a slit 12 there is a continuous area 17 having no slit 12 formed, in the center of the honeycomb structure 10. This continuous area 17 is not exposed to the outer surface of the honeycomb structure, that is, any of the outer surface 13 along the axial direction, the upper end surface 14 and the lower end surface 16. Incidentally, the shape of the continuous area 17 is a rectangle in Fig. 4(a), a circle in Fig. 4(b), a racetrack in Fig. 4(c) and an equilateral tetragon in Fig. 4(d). By forming a honeycomb structure in such a constitution, no cracks are generated in the honeycomb structure even when a large temperature unevenness (for example, large temperature difference between the portions of the honeycomb structure) appears in the whole honeycomb structure.

In each example of Figs. 5(a), (b), (c) and (d), in each section of a honeycomb structure 10 including a slit 12 there is a continuous area 17 having no slit 12 formed and part of the continuous area 17 is exposed to the lower end surface 16 of the honeycomb structure 10.

Figs 6(a) and (b) and Figs. 7(a) and (b) are other examples in which a continuous area is not exposed to the outer surface of a honeycomb structure. Fig. 6(a) is a perspective view and Fig. 6(b) is a sectional view taken along the Y-Y section of Fig. 6(a). Fig. 7(a) is a perspective view and Fig. 7(b) is a sectional view taken along the Z-Z section of Fig. 7(a).

In the example of Figs. 6(a) and (b), the shape of a continuous area 17 is a rectangle as in Fig. 4(a), and the continuous area 17 is not exposed to the outer surface of the honeycomb structure 10. In this example, however, the number of slits 12 is larger than in Fig. 4(a). In the example of Fig. 7(a) and (b), the shape of a continuous area 17 is an ellipse, and the continuous area 17 is not exposed to the outer surface of the honeycomb structure 10.

Next, the constituent features of the honeycomb structure of the present invention are described in more detail.

In the honeycomb structure of the present invention, the length of each slit is preferably 10% or more, more preferably 30% or more of the distance between the outer surface along the axial direction and the center of the honeycomb structure, in a honeycomb structure section which is normal to the through-holes and in which the length of the slit becomes largest.

In the honeycomb structure of the present invention, slits are preferably formed in point symmetry in a honeycomb structure section normal to the through-holes because deformation occurs in the honeycomb structure with substantially no partiality. However, slit formation is not

restricted thereto and slits 12 may be disposed, for example, as shown in Figs. 11 (a) to (d).

Slits 12 may be formed so as to cut partition walls 20 obliquely (not in parallel thereto), as shown in Fig. 8(b).

5 However, slits are preferably formed in parallel to partition walls 20, as shown in Fig. 8(a), because the stress concentration at the front end of each slit 12 is small.

10 When the sectional shape of the through-holes 11 of the honeycomb structure 10 is a triangle, slits 12 are preferably in a direction of  $60^\circ$  or  $120^\circ$ , for the same reason as mentioned above.

15 The width of each slit 12 is not critical and can be determined as desired. However, the width is desirably smaller than the width of each through-hole because too large a slit width incurs increases in filling steps and filling amount of filler and a decrease in the number of cells usable for purification of fluid (e.g. gas).

20 Further in the honeycomb structure 10 of the present invention, it is preferable for relaxation of thermal stress to form, at the front end of each slit 12, a branch part 21 formed by branching, as shown in Fig. 9(b), or a stress relaxation part 22 having a curvature, as shown in Fig. 9(a).

25 The form of each slit 12 may be a form obtained by partially cutting partition walls 20 of a honeycomb structure 10, as shown in Fig. 10(a), or a form obtained by partially removing partition walls 20, as shown in Fig. 10(b).

In the honeycomb structure of the present invention, the sectional shape of each through-hole may be various, for example, a circle, an ellipse and a racetrack.

30 The honeycomb structure of the present invention is

preferably a combination of two or more honeycomb segments. The material constituting the present honeycomb structure preferably contains, as a main crystal phase, at least one kind selected from the group consisting of cordierite, SiC, SiN, alumina, mullite, aluminum titanate and lithium aluminum silicate. SiC of high thermal conductivity is particularly preferred because it releases the absorbed heat easily.

The density of the cells surrounded by partition walls is preferably 6 to 2,000 cells/in.<sup>2</sup> (0.9 to 311 cells/cm<sup>2</sup>), more preferably 50 to 400 cells/in.<sup>2</sup> (7.8 to 62 cells/cm<sup>2</sup>). When the cell density is less than 6 cells/in.<sup>2</sup> (0.9 cell/cm<sup>2</sup>), the resulting honeycomb segments are insufficient in strength and effective GSA (geometrical surface area); when the cell density is more than 2,000 cell/in.<sup>2</sup> (311 cells/cm<sup>2</sup>), the resulting honeycomb segments show a large pressure loss when a gas flows therethrough.

The sectional shape of the through-holes, i.e. the cell shape is preferably any of a triangle, a tetragon and a hexagon from the standpoint of honeycomb production.

With respect to the filler used for filling the slits formed in the honeycomb structure, a ceramic fiber, a ceramic powder, a cement, etc. all having heat resistance are preferably used singly or in admixture. As necessary, an organic binder, an inorganic binder, etc. may be mixed with the filler.

When the honeycomb structure of the present invention is used as a catalyst carrier for purification of the exhaust gas emitted from a heat engine (e.g. an internal combustion engine) or a burner (e.g. a boiler), or for reforming of a liquid fuel or a gaseous fuel, a metal having a catalytic

activity is loaded on the honeycomb segments constituting the honeycomb structure. As representative metals having a catalytic activity, there can be mentioned Pt, Pd and Rh. At least one kind of these metals is preferably loaded on the

5 honeycomb segments.

Meanwhile, when the honeycomb structure of the present invention is used as a filter for capturing and removing the particulate matter contained in a dust-containing fluid, for example, a particulate filter for diesel engine, the

10 honeycomb structure preferably has such a structure that the partition walls surrounding the through-holes has a filtration ability, given proportions of the through-holes are blocked at one end, and the remaining through-holes are blocked at other end.

When a dust-containing fluid is allowed to enter such a honeycomb structure from one end surface, the dust-containing fluid enters the inside of the honeycomb structure from those through-holes not blocked at the above end surface, passes through the partition walls having a filtration ability, and

15 enters other through-holes not blocked at other end surface. During the period in which the dust-containing fluid passes through the partition walls, the particulate matter contained in the fluid is captured by the partition walls, and a particulate matter-free, purified fluid is discharged from

20 the other end surface of the honeycomb structure.

As the accumulation of the captured particulate matter on the partition walls proceeds, plugging appears, which reduces the filtration ability of the honeycomb structure. Therefore, the honeycomb structure is periodically heated

25 using a means such as heater or the like, whereby the

30

captured particulate matter are burnt completely and the filtration ability is revitalized. In order to promote the burning of the particulate matter during the revitalization, it is possible to allow the honeycomb structure to load the above-mentioned metal having a catalytic action.

The present invention is described in more detail below by way of Examples. However, the present invention is not restricted to these Examples.

#### Example 1

By using a SiC-made honeycomb structure having a size of 144 mm (diameter) and 152 mm, a partition wall thickness of 0.3 mm and a cell density of 31 cells/cm<sup>2</sup> and by blocking given proportions of the through-holes at one end and the remaining through-holes at other end, there were produced honeycomb structures each as a particulate filter for purification of diesel engine exhaust gas. They were produced so as to have slits as shown in Fig. 1(a), Fig. 1(d) Fig. 3(a), Fig. 3(b), Fig. 4(a), Fig. 4(b) or Fig. 7, or so as to have no slit (a basic honeycomb structure). In the honeycomb structures of Figs. 1(a) and 1(d), the length of each slit at the upper end surface 14 was 1/2 of the radius of the honeycomb structure 10. In the honeycomb structures of Figs. 1(a) and 3(a), the axial direction length of each slit at the outer surface 13 was 20 mm; in the honeycomb structure of Fig. 3(b), the axial direction outer surface length of each slit formed at the upper end surface 14 was 15 mm and the axial direction outer surface length of each slit formed at the lower end surface 16 was 30 mm.

In the thus-produced honeycomb structures, those cells



in which slits were formed, were sealed with a filler; then, a ceramic-made non-expansion mat (as a holding member) was wound round the periphery of each honeycomb structure; the resulting honeycomb structure was forced into a SUS 409-made  
5 canning case to produce various canning structures. These canning structures were each subjected to the following filter revitalization test. That is, a soot-containing combustion gas generated by burning of a gas oil for diesel engine was allowed to flow into each honeycomb structure from  
10 the lower end surface (the lower end surface in each Drawing) and leave from the upper end surface, whereby the soot in the combustion gas was captured inside the honeycomb structure. The soot-captured honeycomb structure was allowed to cool to room temperature, after which a combustion gas containing a  
15 given proportion of oxygen was allowed to flow into the honeycomb structure from the lower end surface at 800°C to completely burn the soot captured in the honeycomb structure.

The transition period necessary for elevating the inlet gas temperature to 800°C and the weight of the soot captured  
20 were each set at three levels, and the filter revitalization test was carried out. The appearance of cracks was examined at each site of the upper end surface (outlet), lower end surface (inlet), outer surface along axial direction and inside of each honeycomb structure. The results are shown in  
25 Table 1.

Table 1

Soot weight Transition period Site of cracks	Largest			Shortest			Large			Standard		
	Shortest			Short			Short			Standard		
	Inlet	Outlet	Inside	Outlet	Inlet	Outer surface	Inlet	Outlet	Inside	Outlet	Inlet	Outer surface
Fig. 1(a)	▲	▲	▲	▲	▲	▲	○	○	○	○	○	○
Fig. 1(d)	▲	▲	▲	▲	○	▲	○	○	○	○	○	○
Fig. 3(a)	▲	○	▲	○	▲	▲	○	○	▲	○	○	○
Fig. 3(b)	○	○	▲	○	○	▲	○	○	▲	○	○	○
Fig. 4(a)	○	○	▲	○	○	▲	○	○	○	○	○	○
Fig. 4(b)	○	○	○	○	○	▲	○	○	○	○	○	○
Fig. 7	○	○	○	○	○	○	○	○	○	○	○	○
No slit	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲

▲: Cracks generated.

○: No cracks.

As is clear from Table 1, even in the case of the standard conditions, cracks appeared in the honeycomb structure having no slit, at the end surfaces (inlet and outlet). In contrast, no cracks appeared in the honeycomb structures of the present invention of Fig. 1(a), Fig. 1(d), Fig. 3(a), Fig. 3(b), Fig. 4(a), Fig. 4(b) and Fig. 7.

When the transition period was shortened and the weight of the soot captured was increased, temperature unevenness became larger and cracks appeared partially when slits were formed only in the vicinity of one end surface of honeycomb structure as in Fig. 1(a) or Fig. 3(a); however, substantially no cracks appeared when a continuous area was not exposed to the outer surface of honeycomb structure as in Fig. 4(b), and no cracks appeared when slits were formed in an increased number as in Fig. 7.

#### Example 2

Using honeycomb structures shown in Table 2, having the same shapes and sizes as in Example 1 except that the dispositions and lengths of slits were changed, a filter revitalization test of completely burning and removing the soot accumulated was carried out in the same manner as in Example 1. The results are shown in Table 2.

Table 2

Sample No.	1	2	3	4
Structure	Fig. 1(a)	Fig. 3(a)	Fig. 1(a)	Fig. 3(a)
Slit length at end surface	50 mm	15 mm	15 mm	5 mm
Slit length at outer surface	30 mm	15 mm	5 mm	5 mm
Weight of soot captured				
10 g/L	○	○	○	○
12 g/L	○	○	○	X
14 g/L	○	○	X	X
16 g/L	○	○	X	X
18 g/L	○	○	X	X
20 g/L	○	○	X	X
	○	X		

○: No cracks.

X: Cracks appeared.

g/L: gram/liter.

As is clear from the results of Table 2, an increase in weight of soot captured results in an increase in cracks formed when the lengths of slit at end surface and outer surface are smaller than given levles.

A described above, in the honeycomb structure of the present invention, each portion of the honeycomb structure can deform freely without being restricted by other portion even when there is an uneven temperature distribution in the honeycomb structure and, therefore, reduction in thermal stress is possible; as a result, generation of cracks can be prevented.

## Claims

1. A honeycomb structure having a large number of through-holes formed in the axial direction and defined by partition walls, wherein slits are formed so as to be exposed to at least part of the outer surface of the honeycomb structure along the axial direction.
2. A honeycomb structure according to Claim 1, wherein the slits are formed in parallel to the direction of the through-holes.
3. A honeycomb structure according to Claim 1, wherein the slits are formed at least at one end surface at least at the edge.
4. A honeycomb structure according to Claim 3, wherein the length of each slit formed at the edge of one end surface is, in the axial direction of the outer surface, 10% or more of the total length of the honeycomb structure and, at the end surface, 10% or more of the diameter of the honeycomb structure.
5. A honeycomb structure according to any of Claims 1 to 3, wherein each slit is exposed to at least one end surface so as to connect the two points of the end surface edge.
6. A honeycomb structure according to Claim 5, wherein the length of each slit is, in the axial direction of the outer surface, 10% or more of the total length of the honeycomb structure and, at the end surface, 10% or more of the diameter of the honeycomb structure.
7. A honeycomb structure according to any of Claims 1 to 6, wherein each slit is exposed to the outer surface over its total length in the through-hole direction.
8. A honeycomb structure according to any of Claims 1 to 7,

wherein in each section of the honeycomb structure including each slit there is a continuous area in which no slit is formed and which is not exposed to the outer surface of the honeycomb structure.

5 9. A honeycomb structure according to any of Claims 1 to 8, wherein in the honeycomb structure section which is normal to the through-holes and in which the length of each slit is largest, the length of each slit is 10% or more of the distance between the outer surface along the axial direction and the center of the honeycomb structure.

10 10. A honeycomb structure according to any of Claims 1 to 9, wherein in the honeycomb section which is normal to the through-holes and in which the length of each slit is largest, the length of each slit is 30% or more of the distance  
15 between the outer surface along the axial direction and the center of the honeycomb structure.

11. A honeycomb structure according to any of Claims 1 to 10, wherein each slit is filled with a filler.

12. A honeycomb structure according to any of Claims 1 to  
20 11, which is a combination of two or more honeycomb segments.

13. A honeycomb structure according to any of Claims 1 to 12, which is made of a material containing, as a main crystal phase, at least one kind selected from the group consisting of cordierite, SiC, SiN, alumina, mullite, aluminum titanate  
25 and lithium aluminum silicate.

14. A honeycomb structure according to any of Claims 1 to 13, which loads thereon a metal having a catalytic action and is usable for purification of the exhaust gas emitted from a heat engine or a burner, or for reforming of a liquid fuel or  
30 a gaseous fuel.

15. A honeycomb structure according to Claim 14, wherein the metal having a catalytic action is at least one kind selected from Pt, Pd and Rh.

16. A honeycomb structure according to any of Claims 1 to 5 15, wherein the sectional shape of the through-holes is any of a triangle, a tetragon, a hexagon and a corrugation.

17. A honeycomb structure according to any of Claims 1 to 16, wherein the partition walls surrounding the through-holes have a filtration ability, a given proportion of the through-  
10 holes are blocked at one end and the remaining through-holes are blocked at other end.

18. A honeycomb structure according to Claim 17, which is used as a filter for capturing and removing the particulate matter contained in a dust-containing fluid.

## Abstract

A honeycomb structure (10) having a large number of through-holes (11) formed in the axial direction and defined by partition walls, wherein slits (12) are formed so as to be exposed to at least part of the outer surface (13) of the honeycomb structure along the axial direction. In this honeycomb structure, each portion can deform freely without being restricted by other portion even when an uneven temperature distribution appears therein; as a result, reduction in thermal stress is possible and generation of cracks can be prevented.



FIG. 1(a)

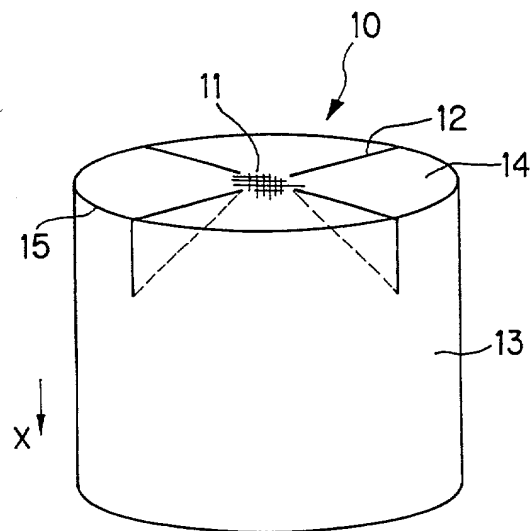


FIG. 1(c)

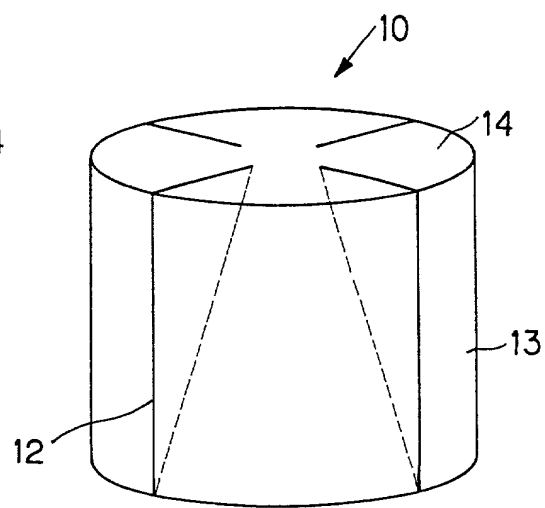


FIG. 1(b)

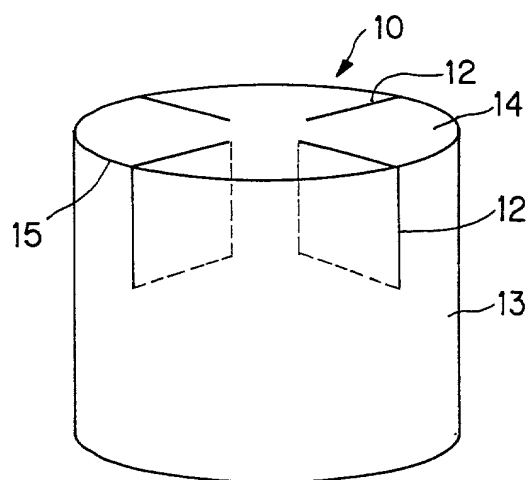


FIG. 1(d)

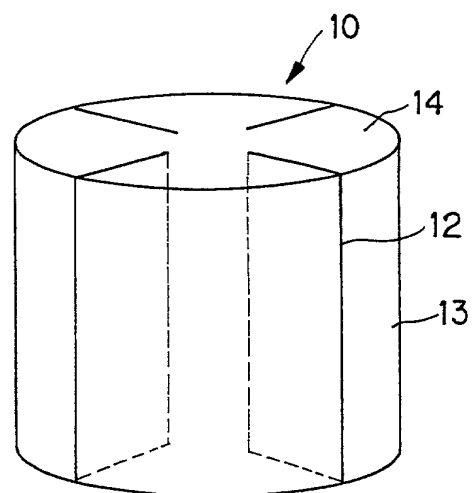


FIG. 2(a)

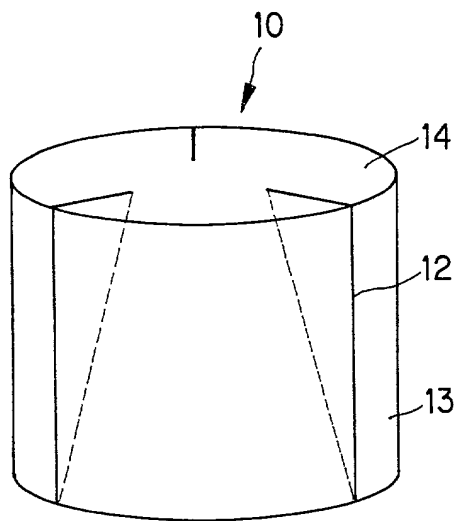


FIG. 2(b)

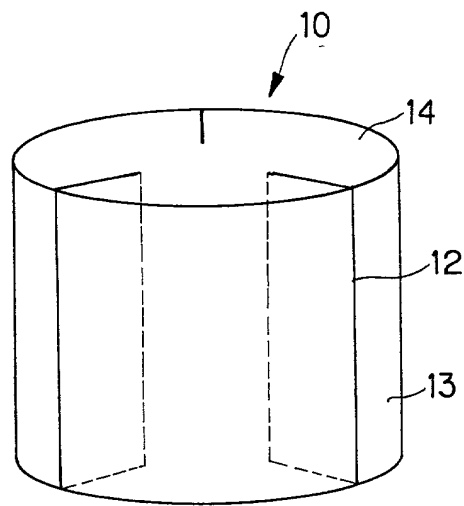


FIG. 3(a)

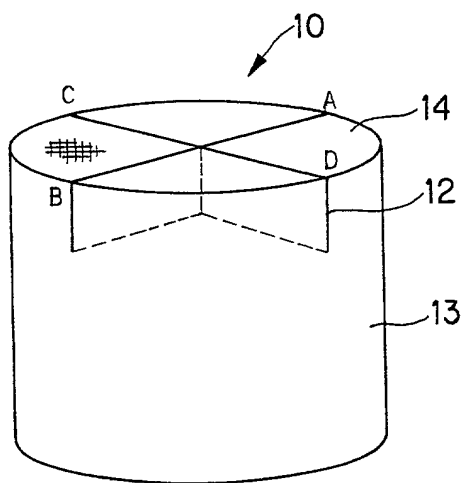


FIG. 3(b)

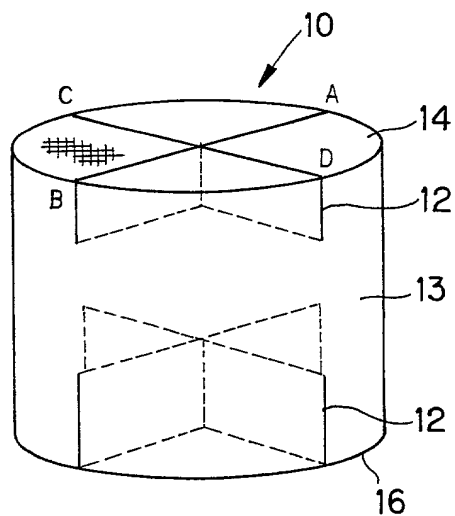


FIG. 4(a)

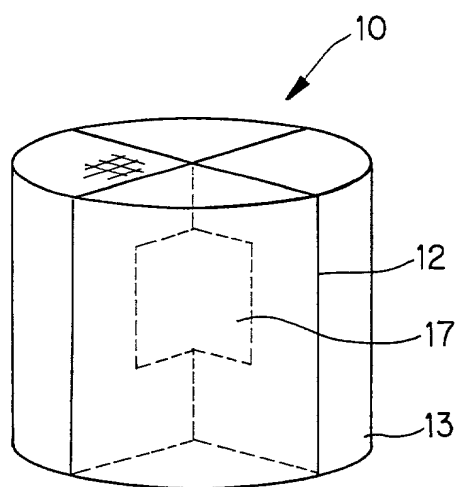


FIG. 4(b)

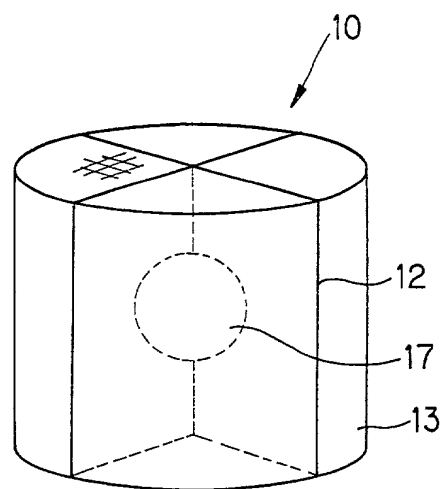


FIG. 4(c)

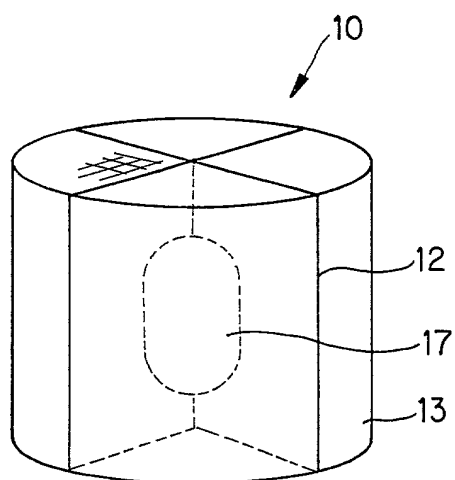


FIG. 4(d)

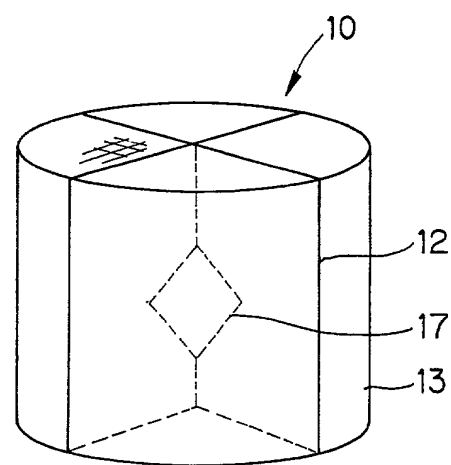


FIG. 5(a)

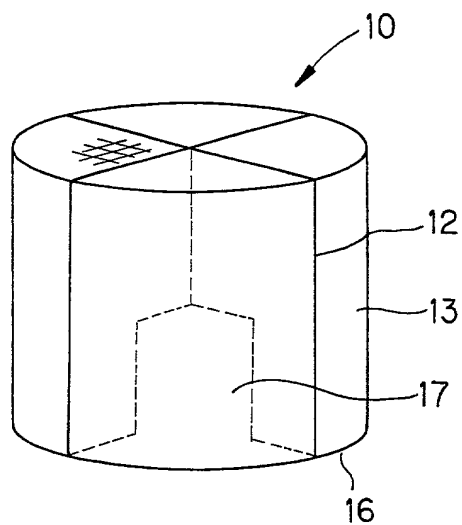


FIG. 5(b)

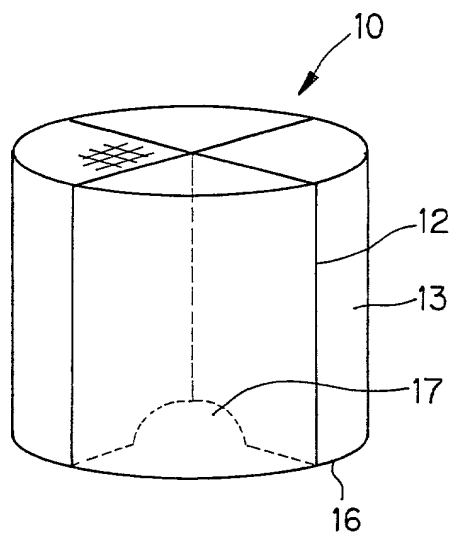


FIG. 5(c)

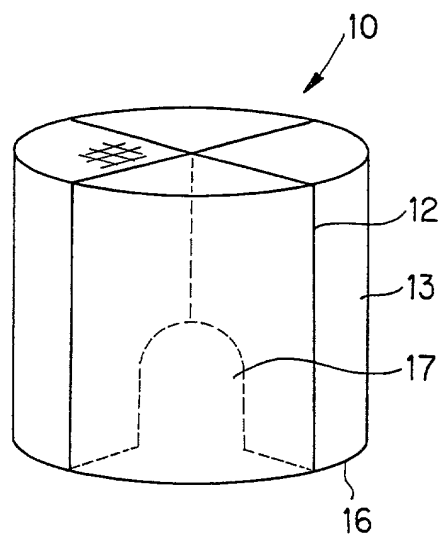


FIG. 5(d)

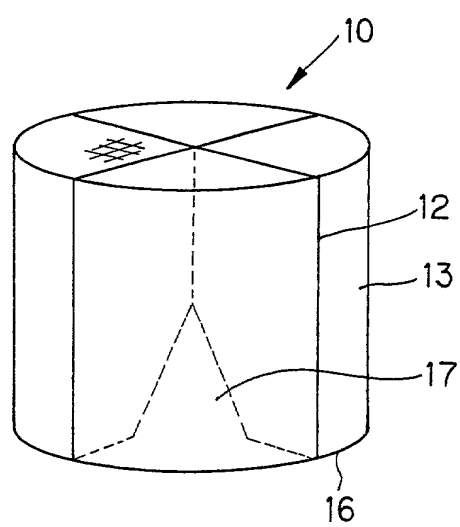


FIG. 6(a)

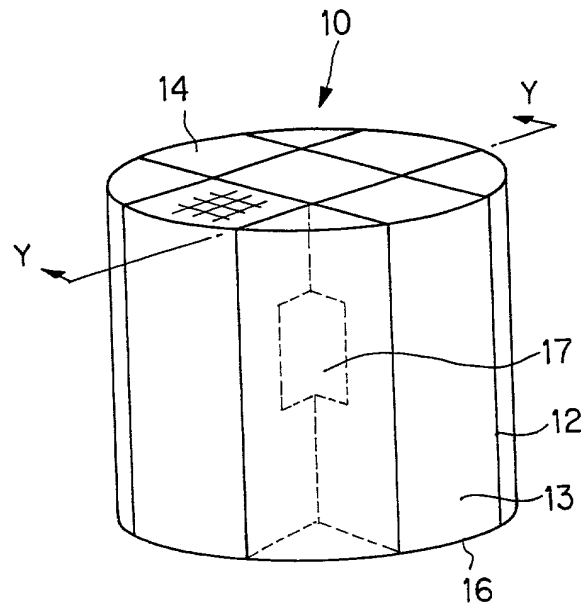


FIG. 6(b)

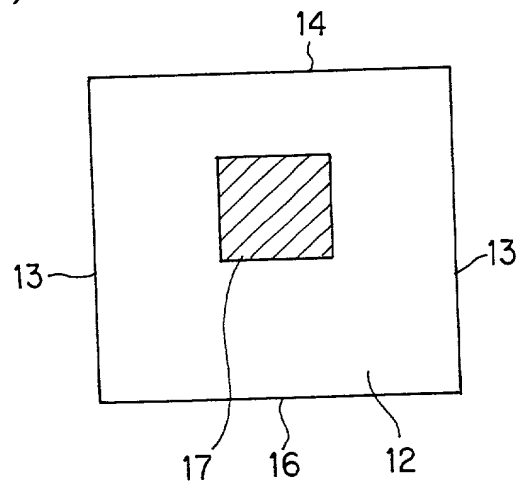


FIG. 7(a)

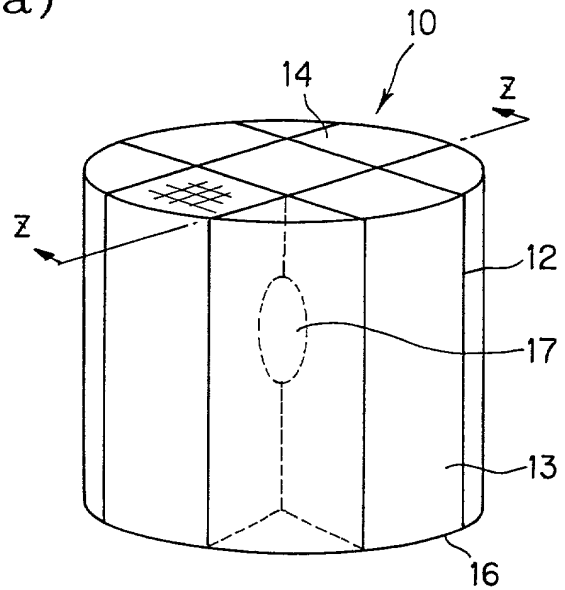


FIG. 7(b)

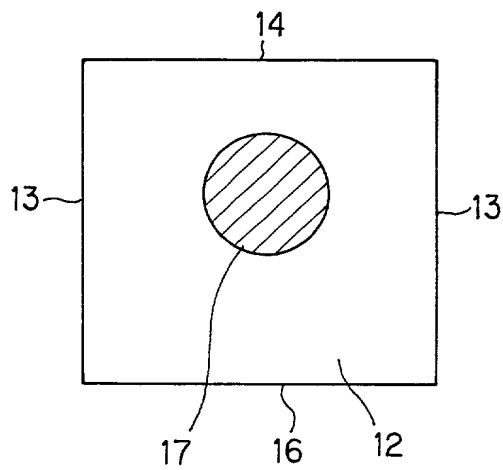


FIG. 8(a)

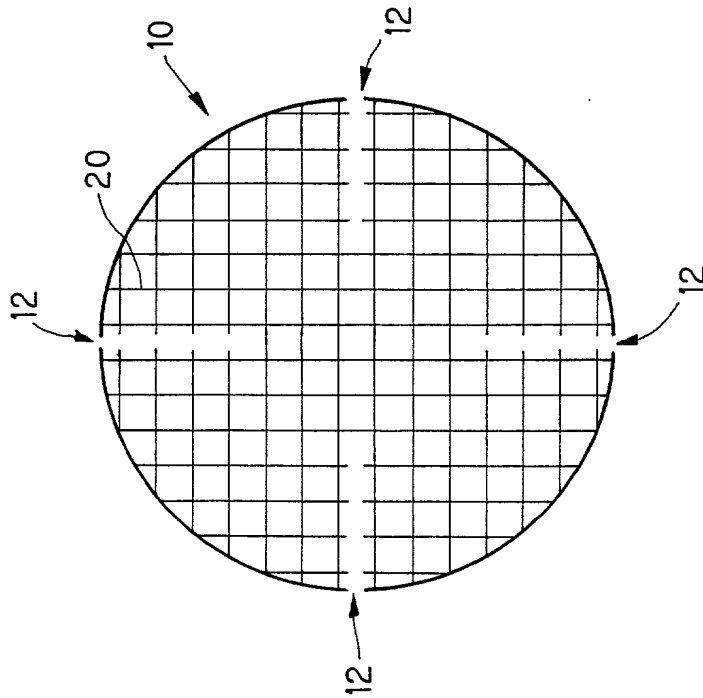


FIG. 8(b)

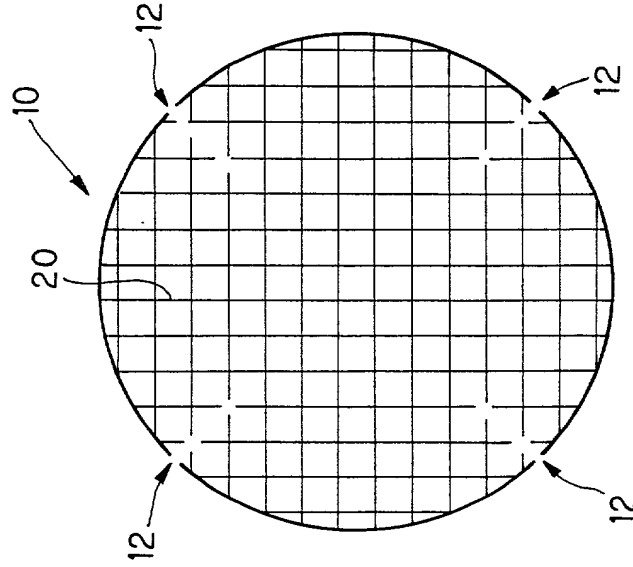


FIG. 9(a)

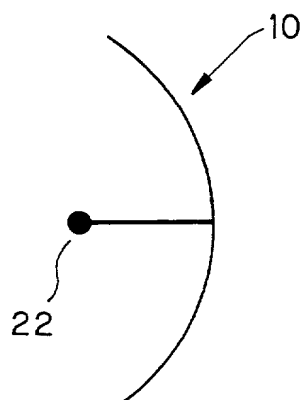


FIG. 9(b)

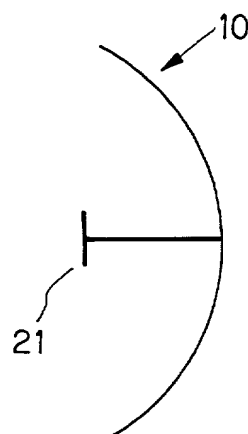




FIG. 10(b)

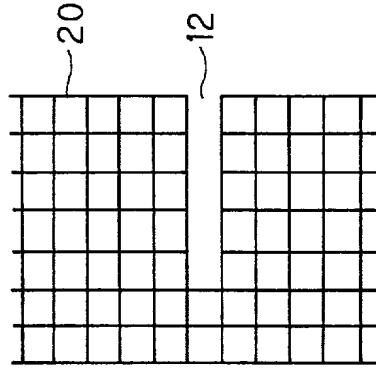


FIG. 10(a)

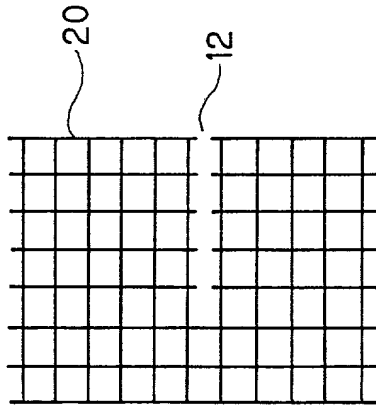


FIG. 11(a)

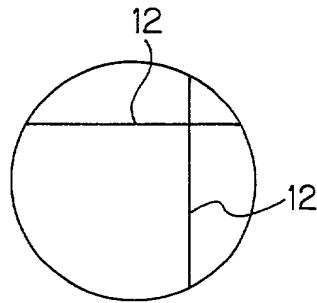


FIG. 11(b)

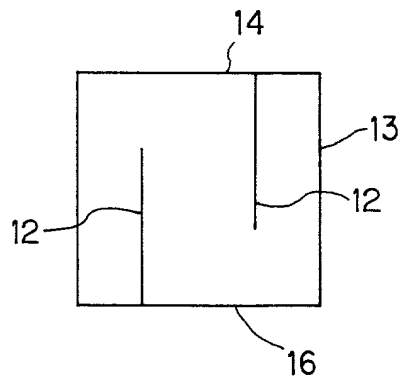


FIG. 11(c)

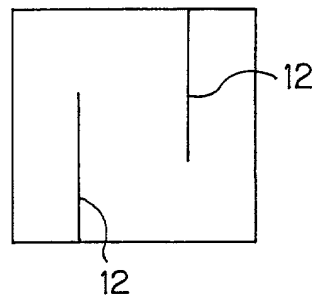
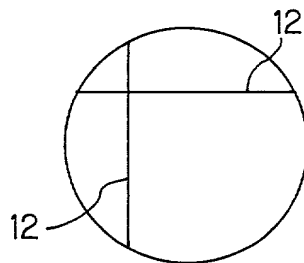


FIG. 11(d)



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WA-056646(1-7)

**Declaration and Power of Attorney  
Under Patent Cooperation Treaty  
35 USC §371(c)(4)**

As a below named inventor, I hereby declare that:

my residence, post office address and citizenship are as stated below next to my name; that

I verily believe that I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural names are named below) of the invention entitled: Honeycomb Structure

described and claimed in the international application number PCT/JP00/08044 filed November 15, 2000 and as amended on \_\_\_\_\_ (if any), the specification and claims of which I have reviewed and understand and for which I solicit a patent.

I acknowledge my duty to disclose information of which I am aware which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a), and that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States of America prior to my international application by me or my legal representatives or assigns, except as follows:

Japanese Patent Application No. 11-329848 filed on November 19, 1999.

The priority of the above applications (if any), filed within a year prior to my international application is hereby claimed under 35 USC 119. I hereby appoint the following as my attorneys of record with full power of substitution and revocation to prosecute this application and to transact all business in the patent office:

Roger W. Parkhurst, Reg. No. 25,177; Charles A. Wendel, Reg. No. 24,453; Lawrence D. Eisen, Reg. No. 41,009.

**ALL CORRESPONDENCE IN CONNECTION WITH THIS APPLICATION SHOULD BE SENT TO:  
PARKHURST & WENDEL, L.L.P., 1421 PRINCE STREET, SUITE 210, ALEXANDRIA, VIRGINIA 22314-2805, TELEPHONE (703) 739-0220.**

I hereby declare that I have reviewed and understand the contents of this Declaration, and that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

3. ☒ Full Name of Sole or First Inventor Takashi HARADA  
Given Name Middle Initial Family Name

\*4. Inventor's Signature *Takashi Harada*

Date of Signature ☒ June 29th, 2001  
Month Day Year

6. Residence Nagoya-city, Aichi-prefecture, Japan  
City SPX State or Province Country

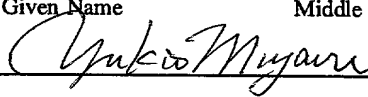
7. Citizenship Japanese

8. Post Office address c/o NGK Insulators, Ltd.  
(Insert complete mailing address, including country) 2-56, Suda-cho, Mizuho-ku, Nagoya-city, Aichi-prefecture, 467-8530 Japan

\*IF THERE IS MORE THAN ONE INVENTOR USE PAGE 2 AND PLACE AN "X" HERE ☒.

PAGE 2 OF U.S.A. DECLARATION FORM  
(Discard this page in a sole inventor application)

00400812 US  
WA-0365 USC27

3	Typewritten Full Name of Second Joint Inventor (if any)	<u>Yukio</u> Given Name			<u>MIYAIRI</u> Middle Initial	<u>MIYAIRI</u> Family Name
*4	Inventor's Signature					
5	Date of Signature	<u>June</u> Month	<u>29th,</u> Day	<u>2001</u> Year		
6	Residence	<u>Nagoya-city,</u> City	<u>52X Aichi-prefecture,</u> State or Province	<u>Japan</u> Country		
7	Citizenship	<u>Japanese</u>				
8	Post Office Address (Insert complete mailing address, including country)	<u>c/o NGK Insulators, Ltd.</u> <u>2-56, Suda-cho, Mizuho-ku, Nagoya-city,</u> <u>Aichi-prefecture, 467-8530 Japan</u>				
3	Typewritten Full Name of Third Joint Inventor (if any)					
*4	Inventor's Signature					
5	Date of Signature					
6	Residence					
7	Citizenship					
8	Post Office Address (Insert complete mailing address, including country)					
3	Typewritten Full Name of Fourth Joint Inventor (if any)					
*4	Inventor's Signature					
5	Date of Signature					
6	Residence					
7	Citizenship					
8	Post Office Address (Insert complete mailing address, including country)					
3	Typewritten Full Name of Fifth Joint Inventor (if any)					
*4	Inventor's Signature					
5	Date of Signature					
6	Residence					
7	Citizenship					
8	Post Office Address (Insert complete mailing address, including country)					

\*Note to Inventors: Please sign name on line 4 exactly as it appears in line 3 and insert the actual date of signing on line 5.

\*\*This form may be executed only when attached to the first page of the Declaration and Power of Attorney form and the specification (including claims) of the application to which it pertains.